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PARTICULATE CONTROL HIGHLIGHTS

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Office of Research and Development

Industrial Environmental Research Laboratory
Research Triangle Park, North Carolina 27711

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ADVANCED CONCEPTS IN ELECTROSTATIC PRECIPITATORS: PARTICLE CHARGING

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ABSTRACT

The objective of this research program was to develop and verify an accurate theory of particle charging for conditions that are typically found in industrial electrostatic precipitators. A new theory was developed, in which the thermal motion of ions is assumed to dominate the charging process. The theory was shown to agree with published experimental data to within 15%. In order to further verify the new theory, experimental determinations of particle charging were made using a mobility analyzer to find the end points of particle trajectories in an electric field. For particles of 0.32 to 7 micrometers diameter, the agreement between theory and experiment was found to be within 20%.

THE COVER:
The Lichtenberg figure shown in the illustration was produced by placing a photographic emulsion in the path of an electrical breakdown streamer occurring during high intensity corona conduction. The splitting into very fine branches is characteristic of breakdown conduction paths, especially near the positive electrode. In many instances the performance limits of an electrical corona system are defined by its breakdown characteristic.

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ADVANCED CONCEPTS IN ELECTROSTATIC PRECIPITATION: PARTICLE CHARGING

The first successful application of the principles of electrostatic precipitation to the removal of suspended particulate material from industrial exhaust gas streams occurred in the first decade of this century. Since that time a technology has emerged which now serves as an important element in the control of air pollution from industrial sources. The results of recent studies indicate that further developments in electrostatic precipitation technology may be derived from an improved understanding of the fundamental processes involved.

The Particulate Technology Branch of the U. S. Environmental Protection Agency Utilities and Industrial Power Division is responsible for an ongoing program of research and development for the purpose of exploring possible advances in the technology. The scope of this program ranges from theoretical and laboratory studies of basic processes to field demonstrations of new systems and techniques.

The operation of electrostatic precipitators is based upon the fact that a charged particle located in an electric field will experience a force which is proportional to the product of the strength of the electric field and the quantity of electric charge on the particle. In conventional electrostatic precipitators an electric field is established in such a manner that the electrostatic force acting upon the suspended particles is perpendicular to the direction of flow of the flue gas through the precipitator. Particles are thus driven out of the gas stream and collected on large metal surfaces. Because the rate of particle collection depends on the magnitude of the electrostatic forces on the particles, any increase in the electric field strength or in the particle charging rate will result in an improved particle collection efficiency (see Figure 1).

This report concerns theoretical and experimental investigations into the particle charging process, and the implications of the results of these studies on the further development of the electrostatic precipitator technology.

PARTICLE CHARGING PROCESS

In an electrostatic precipitator, particles become charged through collisions with ions produced from gas molecules by an electrical corona discharge. A segment of a conventional precipitator might be viewed, in a simplified form, as a pair of vertical parallel plates with evenly spaced vertical wires in the plane midway between the plates (Figure 2). The plates are electrically grounded and a high voltage is applied to the wires. Because of the shape and placement of the wire and plate electrodes, the applied voltage produces an electric field between them which is strongest near the wire. Some of the gas molecules close to the wires are ionized by the effects of the intense electric field. If the voltage on the wire is negative, as in most industrial precipitators, positive ions will be attracted toward the wire, and negative ions will be repelled toward the grounded plates. Since the ionization occurs very near the wires, most of the space between the plates will contain negative ions. The gas from which dust particles are to be removed is forced to flow horizontally between the plates of the precipitator. Upon encountering the negative ions, the particles become charged, and may then be driven by the electric field toward the grounded plates.

It is easy to see how an ion may reach the surface on an electrically neutral dust particle and be deposited on it by a simple collision process. But in order to provide for efficient electrostatic precipitation, it is generally necessary for each particle to accumulate many times the charge of a single ion. The addition of charges of the same polarity to a charged particle requires the action of forces to overcome the electrostatic repulsion between the charged particle and the ions. In an electrostatic precipitator, energy is available in two specific forms to provide for particle charging. One source of energy is the applied electric field, and the other is the random thermal motion of the gas molecules and ions.

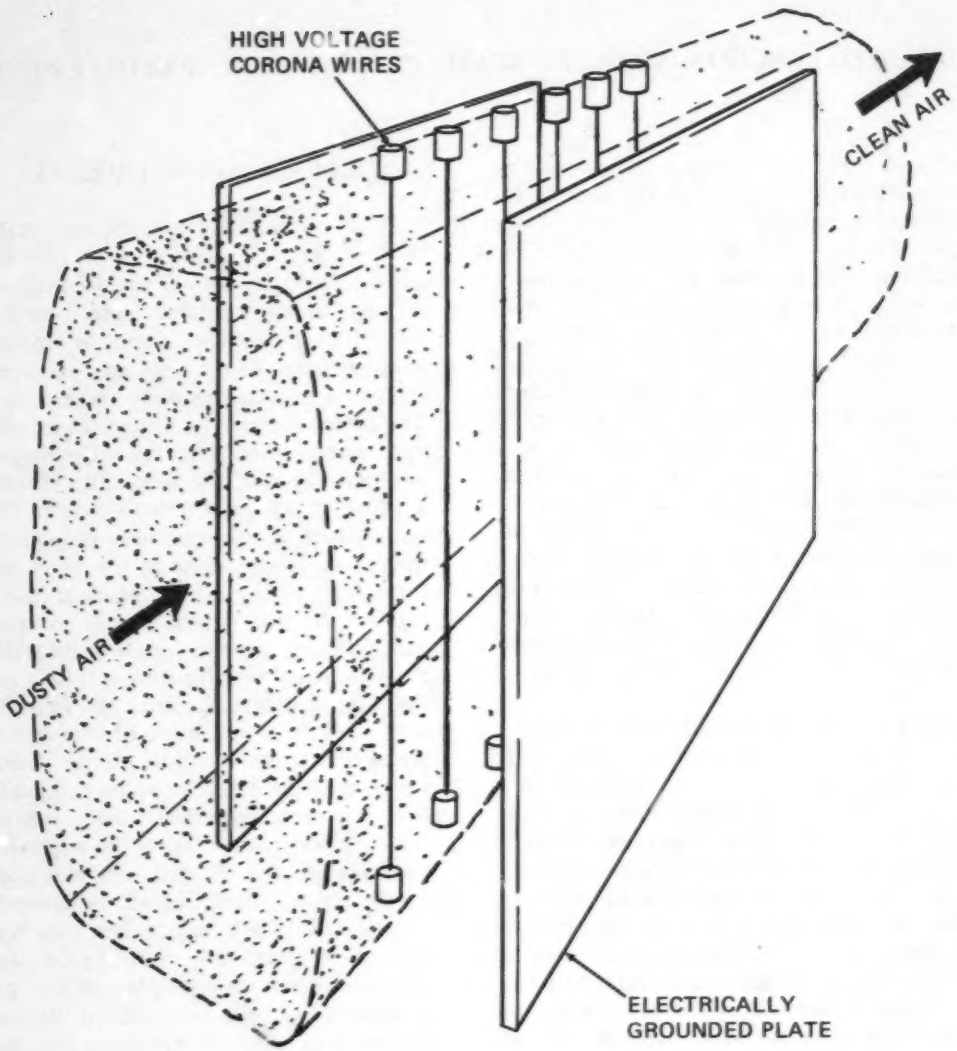

Figure 1. The Basic Precipitation Process. Particles charged by electrical corona discharge current are forced toward the plates by a strong electric field near each plate.

Early in the development of particle charging theories, electric field effects and thermal, or diffusion, effects were dealt with separately. It was found that the particle charging process may be described adequately for particles less than about 0.2 μm in diameter by a theory based entirely on the thermal motion of the ions, without regard to the presence of an electric field. Such an approach is justified on the grounds that the thermal energy of an ion is much greater than the energy which can be derived from even a very strong electric field acting on an ion in a gas. But the random thermal motion involves frequent collisions between ions and gas molecules, so that the average distance between collisions is only about 0.1 μm. For a charged particle several micrometers in diameter the effective range of the repulsive force on an ion is many times greater than the mean free path of the ion. On this larger scale, the longer-range, directed force due to the applied electric field provides the more effective mechanism for particle charging.

Separate theories for particle charging, each limited in applicability, are useful in delineating the nature of the operative charging mechanisms, but for particle diameters between approximately 0.2 and 2.0 μm neither the field charging theory the diffusion charging theory, nor a sum of the two, provides satisfactory agreement with experimental results.

A more comprehensive theory has been derived, taking into account simultaneously the effects of ion diffusion and the applied electric field. Although the electric field makes a small contribution to the kinetic energy of an ion, the most important effect of the field is upon the distribution of ions in the system. In the vicinity of a particle the electric field consists of that resulting from the applied voltage plus a contribution due to the charge on the particle, polarized by the applied field. The theoretical approach employed is to determine the ion density distribution near a particle in terms of the local electric field, and then calculate statistically the rate at which ions reach the particle due to their thermal velocities. The theoretical charging rate cannot, in general, be expressed in a closed, algebraic form, but requires the use of a computer to carry out the calculation.

The charging theory indicates that the total charge accumulated by a particle is strongly dependent upon the electric field strength, the

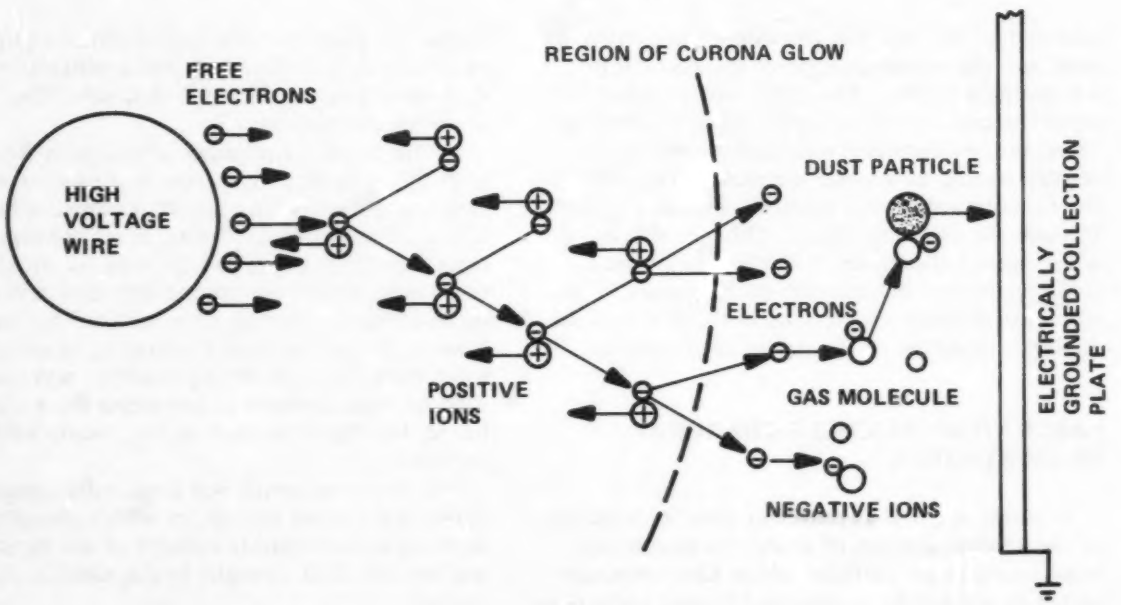

Figure 2. Particle charging process in a corona discharge system.

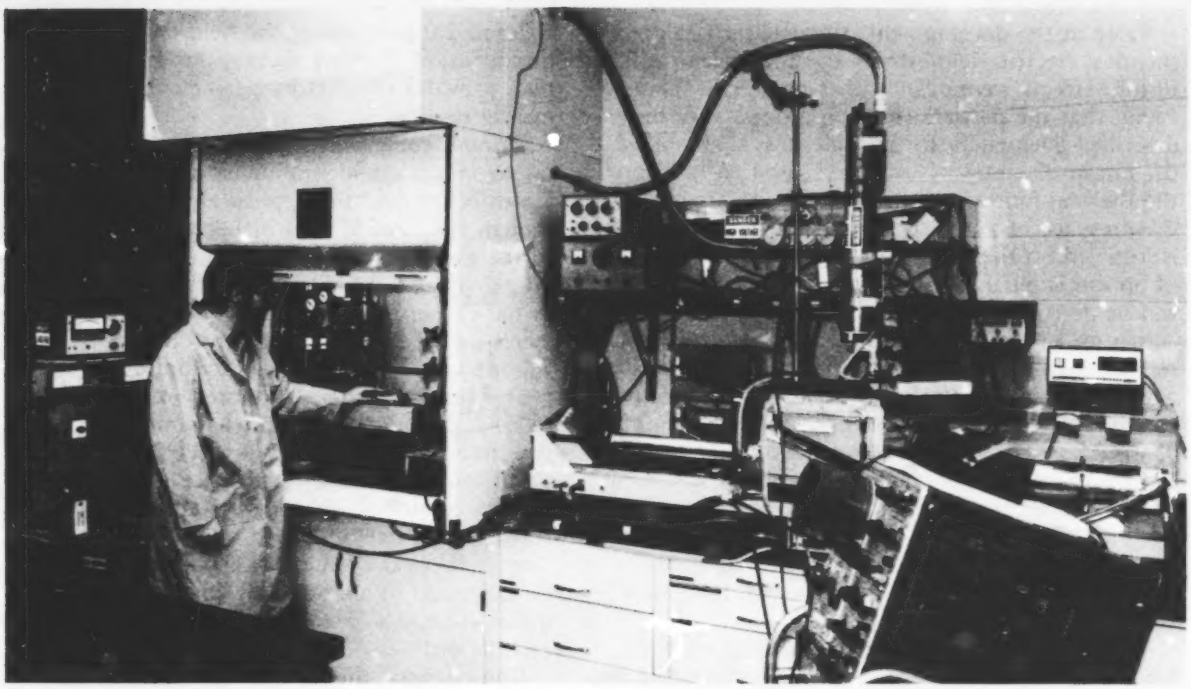

Figure 3. Laboratory apparatus for particle charging experiments.

diameter of the particle, the numerical density of ions, and the residence time of the particle in the charging region. The latter two variables invariably occur as a product in charging theories. Thus, the ion density-residence time product is usually treated as a single parameter representing the total exposure of a particle to ions as it passes through the charging region. Other variables which have a significant effect on the particle charging process include the gas temperature, the electrical mobility of the ions in the gas, and the dielectric constant of the particulate material.

LABORATORY PARTICLE CHARGING MEASUREMENTS

In order to provide sufficient data for validation of the theory, a series of charge measurements must be made on particles which have been subjected to accurately controlled charging conditions. The apparatus requirements include a source of uniformly-sized particles, a device for charging the particles, and a system for measuring the average charge per particle. The experimental equipment is shown in Figure 3, and a schematic diagram is given in Figure 4 that identifies the main components.

In the experiments done at Southern Research Institute, particles were generated by two methods. One was a dispersal of pre-sized plastic spheres in a liquid suspension by means of an atomizer. The second method was based on a device in which a fine liquid stream containing dissolved aerosol material was broken up into uniform droplets by passage through an orifice vibrating at an ultrasonic frequency. A drying chamber was used with each of these systems to evaporate the excess liquid, leaving an aerosol of dry, nearly uniform particles.

The charging device was a specially designed cylindrical corona system, in which provisions were made for separate control of ion density and electric field strength in the particle charging volume.

Particle charge measurements were made by means of a mobility analyzer, an instrument which permits accurate determination of the end points

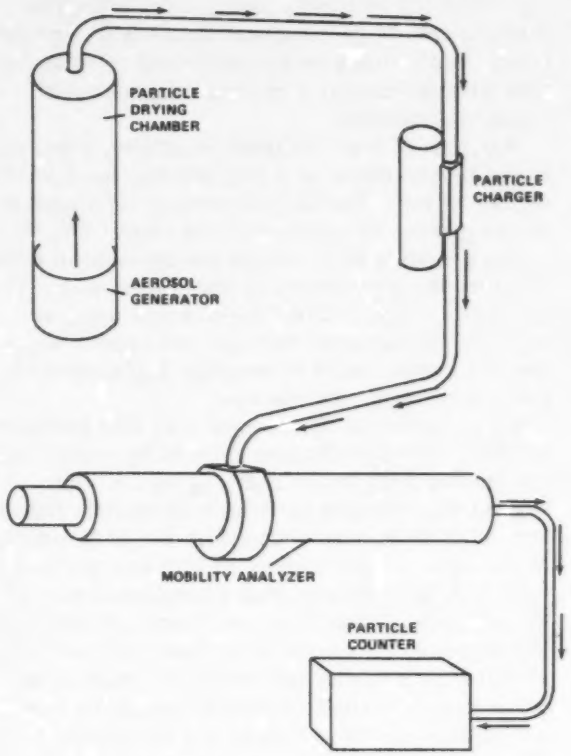

Figure 4. Schematic representation of laboratory apparatus for particle charging experiments.

of the path of a charged particle moving through a smoothly flowing gas stream under the influence of an electric field perpendicular to the direction of gas flow. The trajectory of a particle depends on both the aerodynamic properties of the particle and the electrostatic force on the particle. Given the gas flow rate, the voltage applied to the mobility analyzer electrodes, the diameter of the particle and the end points of the trajectory, the charge on the particle can be determined by a straightforward calculation.

In a series of experiments, particles were charged under various conditions, and the resulting charge measurements were compared with theoretical calculations for the same conditions. Values of electric field strength, E, and the product of ion density and residence time, Nt, were selected to span the range of conditions encountered in actual electrostatic precipitators. Measurements were carried out on particles ranging from 0.32 to 7.0 micrometers (μm) in diameter.

The effects of some of the more significant charging parameters are illustrated in Figures 5 and 6. The total charge per particle as a function of electric field strength for polystyrene latex particles of four different diameters is presented in Figure 5. Although many of the experimentally determined values of particle charge, indicated by the plotted symbols, fall slightly short of the theoretical curves for the larger particles, a steady rise in the average charge per particle as the electric field strength increases is evident. By comparing the four curves in this graph at fixed values of electric field strength, it may also be seen that the average charge per particle is approximately proportional to the square of the particle diameter.

In Figure 6 the particle charge is plotted against Nt for four values of the electric field strength. The particles used for experimental verification were dioctyl phthalate droplets, 1.4 μm in diameter. The theory appears to predict values of particle charge which are too low where the electric field is large,

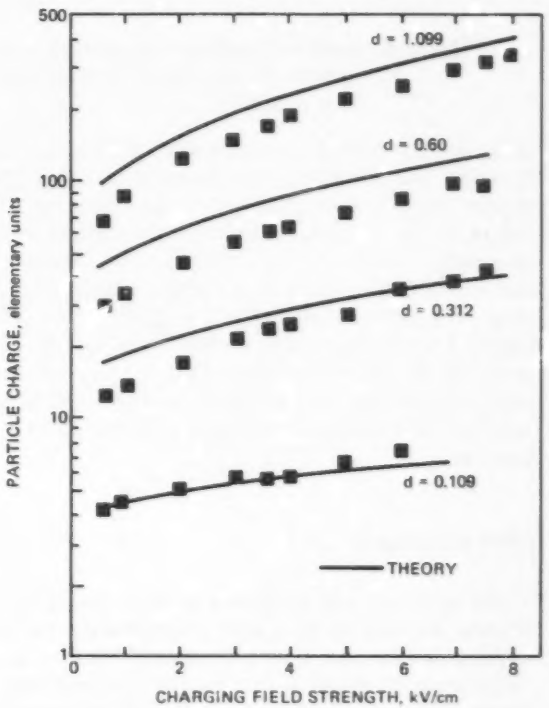

Figure 5. Number of electrical charges per particle vs. charging field strength. Particle diameters (d) are indicated in micrometers.

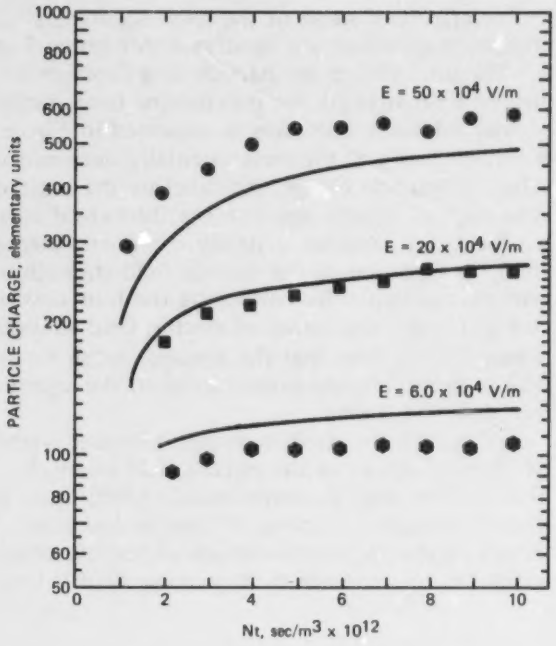

Figure 6. Number of electrical charges per particle vs. ion density-residence time product.

and too high where a small value of electric field is used. But for both experimental and theoretical results there is a distinct saturation charging effect, evidenced by a reduced slope in the curves as Nt increases. Thus, if the current density, and hence the ion density, in an electrostatic precipitator is large, the time required for a particle to become charged to an essentially maximum value may be quite small. In many full-scale precipitators the charging process may be considered complete within the first few inches of the active length of the system.

APPLICATIONS

An accurate and complete particle charging theory, backed by thorough experimental verification, can be useful as a diagnostic tool to determine areas of possible improvement in existing electrostatic precipitators and as a foundation for innovations in the design of new systems.

Some types of dusts and fumes have proven to be especially difficult to collect by precipitation. Among these are particulate materials exhibiting high electrical resistivity and gaseous effluents carrying very large numerical densities of fine particles. Both problems are concerned to some extent with difficulties in maintaining adequate charging conditions.

Materials of high electrical resistivity, when collected on the plates of a precipitator, form localized regions of high electric field strength and corona discharge near the surface of the plate. The ions injected by this back corona are opposite in polarity from those generated at the corona wire. The presence of ions of both positive and negative polarities in the space between the corona wires and the plates results in extreme degradation of particle charging effectiveness.

Large numerical densities of very fine particles interfere with the charging process by modifying the electric field in the charging region. The motion of a charged particle in an electric field is very sluggish in comparison with the drift velocities of the ions. If the number of particles per unit volume is large enough that a substantial part of the electrical charge between the corona wires and plates resides on the particles, then the slow movement of the particles will result in a buildup of space charge in areas where ions would be swept out quickly by the action of the electric field. As the nearly stationary charge distribution increases in the vicinity of the corona wires, the electric field is diminished, resulting in reduced ion generation. In severe cases the corona discharge may be quenched entirely.

The existence of problems of the sort described in the foregoing paragraphs complicates the engineering work involved in electrostatic precipitator design. Predictions of performance based simply on total effluent gas volume and precipitator plate area may fail completely if the specific characteristics of the particulate material are not taken into account.

In coal-fired power plants, the increased use of low-sulfur western coal is accompanied by problems in the collection of high-resistivity fly ash. Metallurgical processes produce a wide variety of dusts and fumes. It is therefore necessary, in designing an electrostatic precipitator for a new application, to characterize the effluent as completely as possible. Conventional approaches to the design problem may be inappropriate for some sources of pollution.

In some applications a relatively simple modification of the conventional technology may be sufficient. For example, the use of specially

designed corona discharge electrodes in place of straight wires may provide an increased corona current and concomitantly higher ion density. For especially troublesome dusts, a two-stage precipitator (Figure 7) may be effective. In such a device the charging and collecting processes are separate. By using a high current density in the charging stage, the particles can be brought to a high state of charge in a very short part of their paths through the system. The charging stage could, therefore, be relatively small, and extraordinary measures could be taken to control particle charging problems which cannot be dealt with economically in a conventional single-stage precipitator. The collecting stage of such a system could be operated at a low current density and high electric field strength, since charging is already accomplished. A concept of this type offers flexibility in design, particularly in the methods which may be used to deal with problem dusts in the charging stage.

As the scope of electrostatic precipitator applications is broadened the results of fundamental investigations into the particle charging and collection processes will form a basis for the development of the necessary new techniques. To this end the Particulate Technology Branch of the U. S. Environmental Protection Agency is continuing to identify problem areas and to pursue the research necessary to deal effectively with all aspects of particulate emission control from stationary sources.

** A more detailed description of the charging studies is given in: "Fine Particle Charging Experiments", D. H. Pontius, Larry G. Felix, J. R. McDonald, and W. B. Smith. EPA-600/2-77-173. August 1977.*

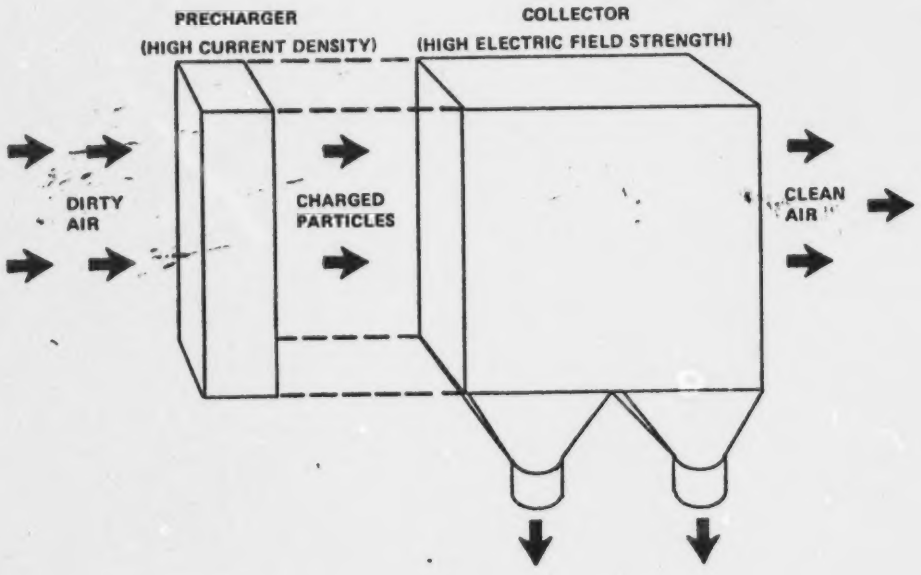

Figure 7. Two-stage electrostatic precipitator concept.